Electrically pumped mid-IR optical frequency combs for dual frequency spectroscopy

Completed Technology Project (2018 - 2021)

Project Introduction

In this work, we propose to develop a fully integrated mid-Infrared optical frequency comb source that spans over 200 nm spectral bandwidth at 3-4 micrometer. Combining revolutionary advances in dual frequency comb spectroscopy (DFCS) with the developed semiconductor mid-IR frequency comb, we will develop a powerful new tool for understanding the origin and evolution of the Solar System and habitability therein. This new in-situ measurement concept will provide a miniature and low power instrument for in-situ measurements of trace gas and stable-isotope compositions on the Moon, Venus, Mars, and Titan as well as such measurements on returned Martian, lunar, and cometary samples. Our team has recently demonstrated the first semiconductor-based mid-IR optical frequency comb by passive mode-locking an interband cascade laser (ICL)[1]. Our demonstrated ICL-based comb is the first true mode-locked semiconductor laser at mid-IR that can access 3-6 micrometer with broad coverage and high efficiency. However, we have identified the modal dispersion in these combs limit the stable operating conditions to a narrow range [2]. In this work, we propose to extend the emission bandwidth and stable operating conditions of the ICL combs by dispersion compensation engineering of the laser gain medium and the waveguide. The proposed optical frequency comb will span over 200 nm with a center wavelength at 3.3 micrometer. By taking advantage of a multi-heterodyne architecture where two nearly similar optical combs are interfered on an optical detector, we will enable a multi-species massively parallel optical detection scheme with part-per-billion (ppb) sensitivity at sub-second acquisition time [3]. Therefore, the proposed dual comb spectrometer is suitable for simultaneous detection of a series of target molecules such as CH_4, H_2S, N_2O, NH_3, C_2H_2, C_6H_6 (benzene) and many other volatile compounds. The innovative combination of high-efficiency ICL combs and small cavity dimensions will be applicable throughout the 3 to 6 micrometer range. The incumbent state-of-the-art in in-situ detection of planetary volatiles is GC-MS (mass spectrometry coupled with a gas chromatographic column). Typical detection limits of GC-MS instruments that are compatible with planetary exploration are approximately a few ppb to 10 ppb. Our proposed instrument will have comparable or better sensitivity. Moreover, IR spectroscopy is inherently compound-specific and isotope-specific, thereby eliminating isobaric interferences associated with mass-spectrometric techniques. Consequently, unlike mass spectrometry, our proposed DFCS instrument does not require sample preparation, pre-concentration, pre-separation (e.g. by gas chromatography), or pre-conversion, resulting in reduced instrument overhead and complexity and avoids issues associated with sample contamination and damage. The Decadal Survey [4] identifies specific goals and objectives for the New Frontiers Saturn Probe mission, that include determining the noble gas abundances and isotopic ratios of H, C, N, and O in Saturn's atmosphere and determining the atmospheric structure at the probe descent location. In a Saturn Probe configuration, our proposed DFCS would be able to measure both Nitrogen/ammonia (lambda = 3.3

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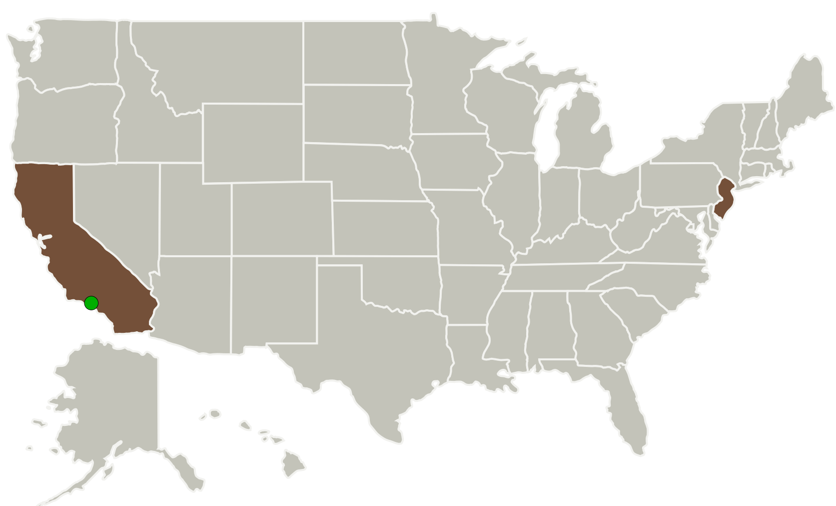
micrometer) and Carbon/methane (lambda = 3.27 micrometer) simultaneously where as other technologies such as tunable laser spectroscopy would require individual channels (2 lasers) for each gas under investigation. [1] M. Bagheri, et al., "Electrically pumped mid-infrared optical frequency combs," submitted to Nat. Comms. (2017). [2] L. Sterczewski, et al., "Dispersion and modelocking properties of interband cascade lasers," in prep. [3] L. Sterczewski, et al., "Multiheterodyne spectroscopy with interband cascade lasers," Opt. Eng. 57 (2017). [4] Vision and Voyages for Planetary Science in the Decade 2013-2022, National Research Council, The National Academies Press, Washington, D. C., 2011.

Anticipated Benefits

This new in-situ measurement concept will provide a miniature and low power instrument for measurements of trace gas and stable-isotope compositions on the Moon, Venus, Mars, and Titan as well as such measurements on returned Martian, lunar, and cometary samples with low concentrations (few parts per mil) and varying isotopic composition.

Primary U.S. Work Locations and Key Partners



Organizational Responsibility

Responsible Mission Directorate:

Science Mission Directorate (SMD)

Lead Organization:

California Institute of Technology (CalTech)

Responsible Program:

Planetary Instrument Concepts for the Advancement of Solar System Observations

Project Management

Program Director:

Carolyn R Mercer

Program Manager:

Haris Riris

Principal Investigator:

Mahmood Bagheri

Co-Investigators:

Siamak Forouhar
Gerard Wysocki
Mathieu Fradet
Clifford F Frez
Karen R Piggee

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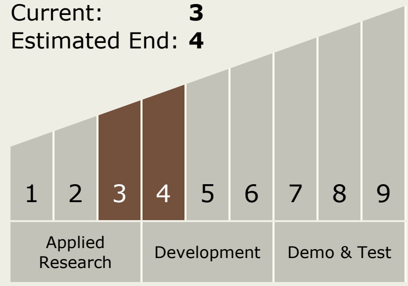
Organizations Performing Work	Role	Type	Location
California Institute of Technology(CalTech)	Lead Organization	Academia	Pasadena, California
Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, California
Princeton University	Supporting Organization	Academia	Princeton, New Jersey

Primary U.S. Work Locations	
California	New Jersey

Technology Maturity (TRL)

Start: **3**
Current: **3**
Estimated End: **4**



Technology Areas

Primary:

- TX08 Sensors and Instruments
  └─ TX08.3 In-Situ Instruments and Sensors
    └─ TX08.3.4 Environment Sensors

Target Destination

Others Inside the Solar System